INTERNATIONAL STANDARD

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Liquid flow in open channels — Sediment in streams and canals — Determination of concentration, particle size distribution and relative density

Mesure de débit des liquides dans les canaux découverts — Sédiments dans les cours d'eau et dans les canaux — Détermination de la concentration, de la distribution granulométrique et de la densité relative

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 4365 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 6, *Sediment transport*.

This second edition cancels and replaces the first edition (ISO 4365:1985), which has been technically revised.

Introduction

In dealing with problems of sedimentation and sediment transport, knowledge of the concentration and the characteristics of the sediment, such as particle size distribution and relative density, is of great importance. For this purpose, sediment samples are collected by suitable samplers and analysed in a laboratory. The results of the analysis are used in the calculation of sediment load, mean diameter and other characteristics.

Liquid flow in open channels — Sediment in streams and canals — Determination of concentration, particle size distribution and relative density

1 Scope

This International Standard specifies methods for determining the concentration, particle-size distribution and relative density of sediment in streams and canals.

NOTE The detailed methods of analysis are set out in the annexes. Annexes A, B and C deal with the determination of the suspended sediment concentration by evaporation and filtration. Annexes D and E deal with the particle-size analysis of suspended sediment and outline the procedures for the bed-load and bed material sediment, respectively. Annex F deals with the determination of the relative density of sediment and Annex G with the determination of particle size distribution characteristics.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 772, *Hydrometric determinations — Vocabulary and symbols*

ISO 4363, *Measurement of liquid flow in open channels — Methods for measurement of characteristics of suspended sediment*

ISO 4364, *Measurement of liquid flow in open channels — Bed material sampling*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 772 and the following apply.

3.1
bed-load
sediment in almost continuous contact with the bed, carried forward by rolling, sliding or hopping

3.2
bed material
sediment of which the stream bed in composed

3.3
bed material load
that part of the total sediment transported consisting of the bed material whose rate of movement is governed by the transporting capacity of the channel

3.4
nominal diameter
diameter of a sphere of the same volume as the given particle

3.5
projected diameter
diameter of the smallest circle that encloses the projected image of a particle when viewed in the plane of maximum stability

3.6
sediment concentration
ratio of the mass or volume of dry sediment in a water-sediment mixture to the total mass or volume of the suspension

NOTE When reporting, it is necessary to mention whether mass concentration or volume concentration is reported.

3.7
sedimentation diameter
diameter of a sphere having the same relative density and terminal settling velocity as a given particle in the same sedimentation fluid

3.8
sieve diameter
width of a square opening through which the given particles will just pass

3.9
relative density
ratio of the mass of a given volume of sediment to the mass of an equal volume of water

3.10
suspended load
that part of the total sediment transported which is maintained in suspension by turbulence in the flowing water for considerable periods of time without contact with the streambed

NOTE The sediment moves practically with the same velocity as that of the flowing water. It is generally expressed as a mass or volume per unit of time.

4 Units of measurement

The units of measurement used in this International Standard are those of the International System of Units (SI).

5 Properties of sediment

5.1 General

The transport of sediment depends as much upon the properties of the sediment as upon the hydraulic characteristics of the flow. The properties of sediment are defined by individual particle characteristics and bulk characteristics.

5.2 Properties of individual particles

Sediment size is the most commonly used parameter to designate the properties of individual particles. While the size of sediment and its packing directly affect the roughness of the bed, the settling velocity of the particles characterizes their reaction to flow and governs the movement of the sediment. This, in turn, depends upon the relative density, shape and size of the particle.

Since particles of natural sediment are of irregular shape, a single length or diameter has to be chosen to characterize the size. Four such diameters, i.e. nominal diameter, projected diameter, sedimentation diameter and sieve diameter, are used for different particle sizes or purposes (for example, sieve diameter for coarse

and medium particles, sedimentation diameter for fine particles that are not usually separated by sieves). The nominal diameter has little significance in sediment transport, but is useful in the study of sedimentary deposits.

5.3 Bulk characteristics

As sediments consist of large numbers of particles differing in size, shape, relative density, settling velocity, etc., it is essential to find some parameters that can represent the characteristics of the group of particles as a whole. Therefore, a sample of sediment is usually divided into class intervals according to characteristics (size, settling velocity, etc.) and the percentage by mass of the total in each interval is determined for the particular characteristic. Frequency distribution curves can be drawn from these data and the sediment parameters (mean, standard deviation, etc.) determined.

6 Sampling

Samples of suspended sediment shall be collected as specified in ISO 4363.

7 Suspended sediment concentration

7.1 Methods for determining the suspended sediment concentration

7.1.1 General

Suspended sediment concentrations may be determined by the following methods:

a) evaporation method;

b) filtration method;

c) hydrometer method (also used for determining particle size).

NOTE Although the evaporation method [7.1.1 a)] requires less time, the filtration method [7.1.1 b)] has the advantage that the fractions collected can be photographed on the filters and are available for further examination. However, the filtration method is prone to greater loss of material, whereas in the evaporation method, the ratio of sample mass to tare mass is small. Therefore, no hard and fast guidelines can be provided for the choice of method, and it is necessary to judge each case on its merits.

7.1.2 Evaporation method

The evaporation method is specified in Annex A.

7.1.3 Filtration method

7.1.3.1 The filtration may be carried out using either a filter paper in a conical glass funnel or a glass-fibre filter disc in a Coors or a Gooch crucible, or a fritted glass or an Alundum crucible, with the application of a vacuum aspirator system to accelerate the passage of the filtrate.

The filtration method using a filter paper and a funnel is specified in Annex B.

7.1.3.2 Filter discs of glass fibre made without organic bindings, such as Whatman grade 934 AH or Gelman type A/E or Millipore type AP 40 or equivalent[1)], can be used in a suitable filtration apparatus such as 25 ml to 40 ml capacity Coors or Gooch crucible with adapter.

The filtration method using a glass-fibre filter disk is specified in Annex C.

7.1.3.3 A fritted glass crucible is made of Pyrex[2)] or other resistance glass, the base of the crucible is fusion-fitted with a porous fritted disc insert.

The crucible is available in different porosity grades, such as coarse, medium and fine (of pore size 40 µm to 60 µm, 10 µm to 15 µm and 4 µm to 5,5 µm, respectively). The particular grade should be selected according to the nature of the sample. The method using a fritted glass crucible is specified in Annex C.

7.1.3.4 Filtering Alundum[3)] crucibles are similar in shape and size to Gooch or fritted glass crucibles, but made of fused aluminium oxide.

They are made in three degrees of porosity (coarse, medium and fine) and in two types: plain and ignition. The particular type and porosity are selected according to the nature of the sample and purpose of use.

The method of using Alundum crucibles is similar to that for using glass-fibre filter discs or fritted glass crucibles (see Annex C). However, Alundum crucibles are used without the addition of a filtering medium.

The main advantages of using Alundum crucibles are the following.

a) The crucibles are light, which facilitates greater sensitivity in weighing operations.

b) The tare masses are less subject to change.

NOTE 1 For samples containing a significant quantity of very fine particles, the last two, viz. the fritted-glass and the Alundum crucible method, are less accurate because of the loss of some of the particles during the filtration and the washing stages.

NOTE 2 There are two other methods, in addition to those mentioned above, that have been used to determine sediment concentration: the hydrometer method and a Gooch crucible with an asbestos layer as a filtering medium. The hydrometer method, although rapid, is not accurate when the sediment concentration is not high or the particles settle rapidly. Moreover, the hydrometer is usually calibrated for 19,4 °C and hence needs to be recalibrated for different temperatures. The hydrometer method is specified in D.1.1. Regarding the use of the asbestos layer as a filtering medium in Gooch crucibles, many countries no longer allow the use of asbestos. Moreover, the pore sizes of asbestos are undefined as they depend on the thickness and uniformity of the layer. Some portion of the asbestos can get washed out from the filtration layer, causing loss in accuracy.

7.2 Expression of concentration

The amount of suspended sediment shall be expressed as the mass or volume of dry sediment per unit mass or volume of suspension (i.e. mass/volume or mass/mass etc.).

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1) Whatman grade 934 AH, Gelman type A/E and Millipore AP 40 are examples of a suitable products available commercially. This information is given for the convenience of users of ISO 4365 and does not constitute an endorsement by ISO of this product.

2) Pyrex is an example of a suitable product available commercially. This information is given for the convenience of users of ISO 4365 and does not constitute an endorsement by ISO of this product.

3) An Alundum crucible is an example of a suitable product available commercially. This information is given for the convenience of users of ISO 4365 and does not constitute an endorsement by ISO of this product.

8 Particle-size analysis

8.1 Particle-size analysis of suspended sediment

For particle-size analysis, suspended sediment may be classified in terms of the diameter of the suspended solids as follows:

a) coarse sediment: containing particles with a diameter greater than 0,25 mm;

b) medium sediment: containing particles with a diameter of 0,062 mm to 0,25 mm;

c) fine sediment: containing particles with a diameter less than 0,062 mm.

The methods for analysing suspended sediment of these classes are specified in Annex D.

NOTE In the case of suspended sediment, grading by particle size of the $<$ 0,062 mm fraction is usually not carried out because of the unimportance of accurately separating the small amount of solid particles that generally exist in suspension. If, however, a more precise separation between the coarse and medium sediments is required, the procedure specified in 8.2 for bed-load and bed material can be used. A particle-size analysis procedure for fine sediment is given in E.3.5.

8.2 Particle-size analysis of bed-load and bed material

For the analysis of the bed-load or bed material for particle size distribution and mean diameter of samples, they are classified broadly into those of diameter greater than, and those of diameter less than, 0,5 mm. Classification of material into these two ranges is suitable for the computation of bed-load.

The methods for analysing bed-load and bed material are specified in Annex E.

The particle-size distribution of sediment may be determined by sieving (when particles are all coarse), by a combination of sieving and settling velocity, or indirectly by measuring particle-settling velocities in a column of liquid. It would be advantageous to use only one measure of diameter over the entire range of sizes for all sediments, preferably the sedimentation diameter, but this is not practicable, since large particles will settle very rapidly in the sedimentation liquid. This causes difficulties in dispersion, and would thus require larger equipment. On the other hand, sieve dimensions and the quantity of material available will set a limitation on the size of fine particles. Therefore, in practice, the coarser particles of suspended sediment (diameter greater than 0,25 mm) and the coarser particles of bed-load and bed material (diameter greater than 0,5 mm) are analysed by sieving and all the finer material by sedimentation techniques. This may result in a small abrupt break in the particle size distribution curve, which may be adjusted by the use of the approximate relationship among the diameters, as given in Equation (1):

$$D_{sd} = 0{,}94\, D_{sa} = 0{,}67\, D_{pd} \quad (1)$$

where

D_{sd} is the sedimentation diameter;

D_{sa} is the sieve diameter;

D_{pd} is the projected diameter.

8.3 Expression of the particle-size distribution

8.3.1 Frequency-distribution tables

Frequency-distribution tables should be prepared from size analyses to present the data in an orderly form.

In order to draw up the frequency distribution, the total range of sizes (diameters in millimetres) is divided into intervals, called “class intervals”, the number of which will depend on the classes into which the sample has been divided. The percentage of the total mass of the sample falling within each one of these intervals is tabulated. Thus, if an interval has limits of 0,10 mm and 0,08 mm, the percentage of the total mass of the sample falling within this size range is tabulated and called the frequency of that particular class interval.

For the size distribution of coarser material, particularly for bed-load or bed material, the distribution is obtained with unequal class intervals; but for the size distribution of suspended material, a class interval of 0,02 mm is adopted over the range 0,062 mm to 0,50 mm. Particles larger than 0,50 mm and smaller than 0,062 mm are broadly classified as “class > 0,50 mm” and “class < 0,062 mm”, respectively.

8.3.2 Graphical presentation

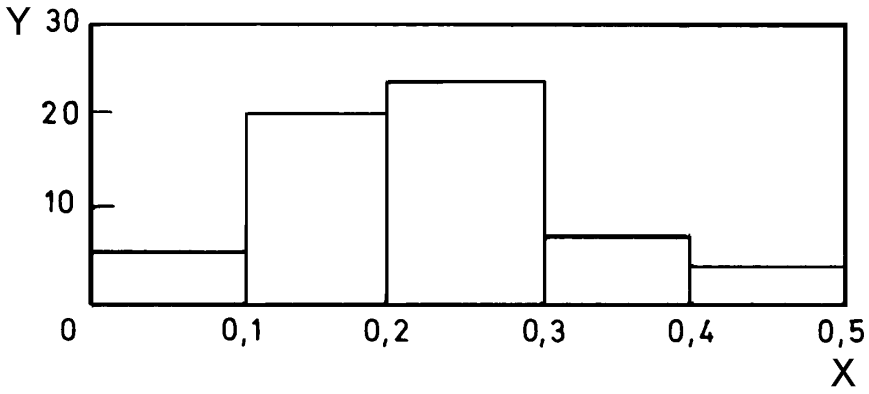
8.3.2.1 The data from a particle-size analysis may be presented in three different graphical forms:

a) as histograms;

b) as frequency polygons and frequency curves;

c) as cumulative curves or particle-size summation curves.

The simplest manner of depicting the results of a mechanical analysis is to prepare a histogram of the data. The diameter, expressed in millimetres, is usually chosen as the independent variable, with the frequency as the dependent variable. In general, the class intervals are the abscissa, and above each class, a vertical rectangle of width equal to the class interval and height proportional to the frequency in the class, is drawn (see Figure 1).



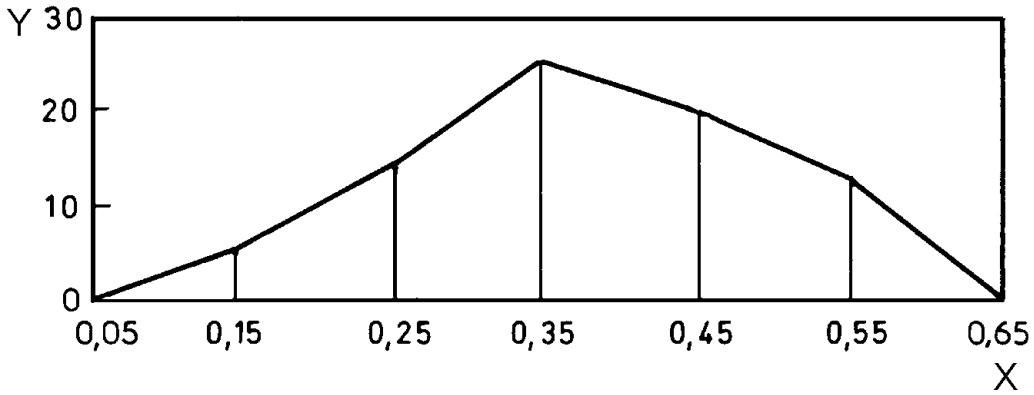
Key

X diameter, expressed in millimetres
Y frequency, expressed in mass percent

Figure 1 — Example of a histogram for the presentation of a particle-size distribution

8.3.2.2 In addition to the use of histograms as frequency diagrams, a common statistical device is to indicate variations in frequency by means of a line diagram instead of rectangular blocks.

Such frequency diagrams are called frequency polygons (see Figure 2).



Key

X diameter, expressed in millimetres

Y frequency, expressed in mass percent

Figure 2 — Example of a frequency polygon for the presentation of a particle-size distribution

8.3.2.3 Cumulative frequency curves readily yield numerical values that serve to describe the properties of the sample in terms of size distribution.

They are based on the frequency analysis of particle sizes, and drawn by choosing a size scale along the horizontal axis, and a frequency scale from 0 % to 100 % along the vertical axis. Either an arithmetic or logarithmic scale can be used for the size. However, the commonest approach is to use a logarithmic scale. In practice, cumulative curves are constructed by plotting ordinates, which represent the total amount of material larger or smaller than a given diameter. Two types of cumulative curves are possible: the “more than” curve and the “less than” curve. Either may be used, as they provide the same type of information. Figure 3 gives an example of a “more than” cumulative curve.

8.3.3 Basic distribution of bed material

The size distribution of bed material more or less follows logarithmic-normal, or lognormal, distribution, i.e. the logarithm of the variable is distributed normally.

Differentiation of the cumulative distribution function leads to Equation (2):

$$P(x)\,\mathrm{d}x = \text{Ø}(u)\,\mathrm{d}u\,\frac{1}{\sigma\sqrt{2\pi}}\exp\left\{-\left[\frac{(\lg x-\lg\varepsilon)^2}{2\sigma^2}\right]\right\}d(\lg x) \tag{2}$$

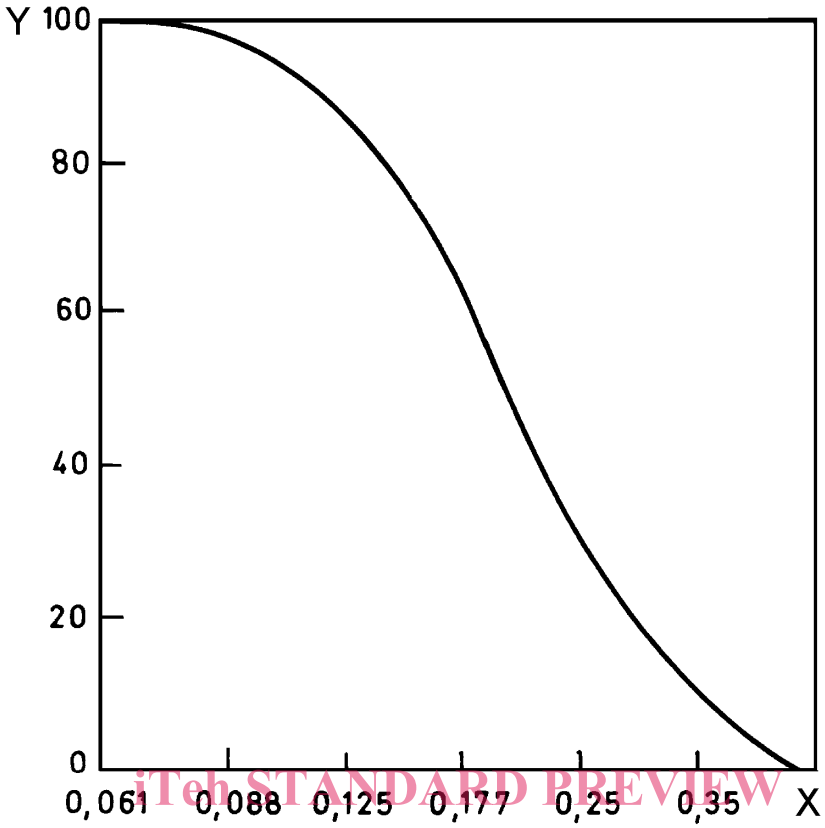
where, by definition,

$$\text{mean } (\lg x) = \lg \varepsilon \tag{3}$$

$$\text{variance } (\lg x) = \text{mean}\left[(\lg x-\lg\varepsilon)^2\right] = \sigma^2 \tag{4}$$

Thus, the symbol ε does not denote the mean of the variable x; lg ε is defined as the mean of lg x.

NOTE The variable x in this case is D, the particle-size diameter.



Key

X diameter (logarithmic scale), expressed in millimetres

Y frequency, cumulative mass percent of particles with a diameter greater than the selected value

Figure 3 — Example of a cumulative frequency curve for the presentation of a particle-size distribution

9 Determination of relative density

The method for determining the relative density is specified in Annex F.

NOTE The density can be computed from a knowledge of the relative density.

10 Determination of particle-size distribution characteristics

The method for determining the particle-size distribution characteristics is specified in Annex G.

11 Data processing

For both manual and automatic data processing, systematic forms and procedures are required, depending on the specific needs.

Annex A
(normative)

Determination of the concentration of suspended sediment by the evaporation method
(for coarse sediment particles)

A.1 Procedure

A.1.1 Determine the volume and the total mass of the sample (sediment + water) plus bottle, with a capacity usually not less than 1 l (except in some countries where a smaller sample size is used) to the nearest 0,5 g. Record this mass as the gross mass.

A.1.2 Allow the sample to stand undisturbed so that the sediment settles out from the suspension. Decant the sediment-free liquid after it appears to the eye to be clear.

A.1.3 Wash the remaining sediment from the bottle, by means of a stream of gravity-fed deionized or distilled water from a wash-bottle, into a previously weighed dry evaporating dish. Loosen the sediment adhering to the sides of the bottle by means of a rubber-tipped glass rod, ensuring that there is no loss of material during this process.

Determine the mass of the empty bottle after drying, using the same balance, and record this as the tare mass.

A.1.4 Dry the sample in the evaporating dish on a steam-bath or in a drying oven. If necessary, add successive sample portions to the same dish after evaporation. The sample should be dried initially at 85 °C to 95 °C to prevent splattering and loss of sample. After it appears dry, then heat the evaporated sample for at least 1 h in an oven at 101 °C to 105 °C, cool the dish in a desiccator to balance temperature and weigh quickly. Repeat the cycle of drying, cooling and weighing until a constant mass is obtained, i.e. until the loss of mass is less than 1 mg. Otherwise, dry the evaporated sample overnight at 101 °C to 105 °C, cool the dish in a desiccator to balance temperature and weigh the dish and contents quickly to the nearest 0,001 g.

A.2 Expression of results

Calculate the amount of suspended sediment, in accordance with Equation (A.1) to determine the mass fraction, w_{ss}, of the suspended solids or in accordance with Equation (A.2) to determine the concentration, C_{ss}, of the suspended solids:

$$w_{ss} = \frac{m_4 - m_3}{m_2 - m_1} \qquad (A.1)$$

where

m_1 is the tare mass, in grams, of the bottle;

m_2 is the gross mass, in grams, of the bottle plus sample;

m_3 is the mass, in grams, of the empty evaporating dish;

m_4 is the mass, in grams, of the evaporating dish plus dried sediment.

